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Electrofishing Distance Needed to Estimate Fish Species Richness in Raftable Oregon Rivers

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Abstract.—One critical issue surrounding river biomonitoring is the minimum amount of sampling distance required to adequately represent the fish assemblage of a reach. Determining adequate sampling distance is important because it affects the estimates of fish assemblage integrity and diversity at the local and regional scales. We sought to answer the sampling distance question by sampling 45 raftable Oregon river reaches for an entire day and then assessing the minimum effort needed to collect 95% of the species obtained in 75% of the reaches sampled. We also resampled 10 reaches to estimate the measurement and sampling period errors. Fish were collected by means of an electrofishing raft, and physical and chemical habitats were sampled to aid in data interpretation. The collected numbers of species were typically only 0–3 species fewer than those predicted for true species richness by simulated species accumulation curves and nonparametric models. We concluded that a sampling distance equal to 85 times the mean wetted channel width produced repeatable results and 95% of the fish species that were usually collected in 100 channel widths or 8 h. Collection of all fish species in a reach was estimated to require an average of 300 channel widths.

The issue of sampling distance sufficiency is important in raftable rivers because of increased interest in monitoring the status and trends of fishes in these systems. Regulatory agencies responsible for monitoring thousands of river miles need consistent and cost-efficient methods for making assessments. Oversampling causes labor costs to be higher than necessary, while undersampling produces inaccurate and imprecise estimates of fish species occurrence and richness—key indicators in estimates of fish assemblage integrity and diversity. To date, however, sampling sufficiency has not been quantitatively evaluated in terms of electrofishing distance for raftable rivers.

Estimates of ‘‘true’’ species richness have long interested ecologists. Palmer (1990) argued that richness estimates based on field studies are usually invalid because of small sample sizes, while simulations rarely mimic the real patterns of species occurrence. He concluded that observed spe-

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cies richness is usually an underestimate because some species are not included in the samples. In comparisons based on field data from 30 sites, Palmer found that nonparametric estimators (jackknife, bootstrap) were more precise and less biased than extrapolations from species−area curves. Bunge and Fitzpatrick (1993) also observed that nonparametric estimators developed from sampling theory provided better estimates of richness than curve extrapolation; they favored the nonparametric estimator of Chao and Lee (1992). Based on 12–121 samples, Colwell and Coddington (1994) favored the Chao, jackknife, and Michaelis-Menten estimators. This and subsequent research led to the development of EstimateS (Colwell 1997), a computer program that calculates multiple species accumulation curves and statistical estimates of true species richness. Hellman and Fowler (1999) compared three nonparametric estimators of true richness and concluded that the second-order jackknife was the least biased for sample sizes less than 25% of all quadrats sampled. The first-order jackknife was least biased for sample sizes of 25–40% of all quadrats sampled, and the bootstrap was least biased for sample sizes of 40–65%. The bootstrap was the most precise of the three at all sample sizes, while it and the jackknife were usually the most accurate. Walther and Morand (1998) concluded that the first-order jackknife was consistently less biased and more precise than the other two. Keating and Quinn (1998) demonstrated that the Michaelis-Menten model performed poorly when there were many species overall and many rare species. Apparently, the appropriateness of any given estimator varies with the species richness and distribution in the sample. The variability among nonparametric estimators applied to the same data sets indicates the wisdom of examining several estimators when estimating true species richness.

Based on research on 4–10 wadeable stream reaches and species-effort extrapolations, electrofishing distances 14–198 times the mean wetted width of the channel were needed to estimate fish species richness at 70% of the reaches (Lyons 1992; Angermeier and Smogor 1995; Paller 1995; Patton et al. 2000). Fourteen channel widths are 1–2 times the meander wavelength and therefore typically incorporate 2–4 riffles and pools in alluvial channels (Richards 1982). Sampling 14–198 times the channel width in larger rivers will often equate to electrofishing well beyond the 500-m distance recommended by Gammon (1976) and Yoder and Smith (1998) to give consistent values for measures of fish assemblage integrity. Such distances also exceed the 500–1,000 m recommended by Meador et al. (1993) and that have been found by Penczak and Mann (1993) to yield no additional species.

Fourteen channel widths may be insufficient to assess fish species richness for a single reach on raftable rivers. In contrast to wadeable streams, raftable rivers are less effectively sampled by electrofishing because of deep waters and large surface areas. Hazardous obstructions, swift water, rapids, and larger, more mobile fish further reduce sampling efficiency. Most river electrofishing crews fish along only one shore of wide rivers, leaving most of the channel and off-channel habitats unsampled. Some researchers employ multiple gears to assess different habitats and capture additional species, but electrofishing is less selective and more widely applicable than the other techniques for monitoring fish assemblages (Hendricks et al. 1980; Thoma 1998; Vaux et al. 2000). Night electrofishing is more effective than day electrofishing in some rivers (Sanders 1992) but is unsafe in high-gradient rivers with many obstructions. All these limitations may mean that sampling more than 14 channel widths is needed to estimate fish species richness precisely and accurately on raftable river reaches.

Our objective was to determine an appropriate raft electrofishing effort for rivers 10–150 m wide with widely varying velocities and habitats ranging from pools many meters deep to riffles a few centimeters deep. Such rivers may or may not have boat launch facilities or road access, and the sites were to be sampled in a single day. The general method and level of sampling effort were to be applicable to raftable rivers throughout the western United States in preparation for a 12-state survey of rivers by the U.S. Environmental Protection Agency (USEPA).

Methods

Sampling design.—We used a spatially balanced randomized sample to select 45 river reaches on 26 Oregon rivers (Herlihy et al. 2000), thereby providing a statewide representative sample and a diverse set of river sizes and physical and chemical habitats (Figure 1; Table 1). Because we can make inferences about all the rivers in Oregon from this random sample, it represents the state's 6,181 km of rivers, 90% of which are 4th to 7th order on 1: 100,000-scale maps. To estimate sampling period and measurement variability, 5–6 reaches each year were chosen randomly for revisits. The sur-

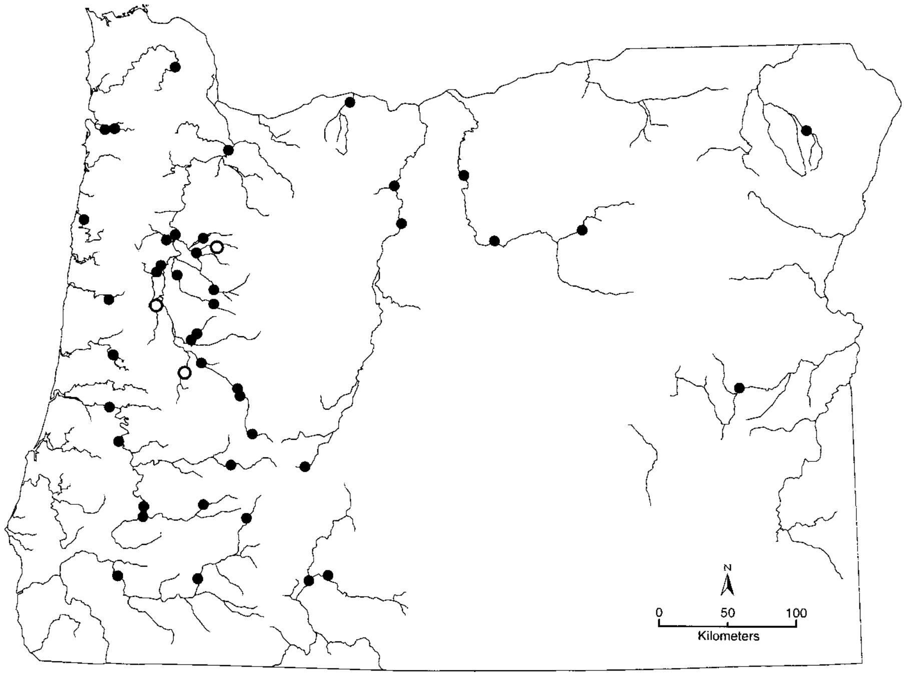

FIGURE 1.—Locations of the 45 randomly selected Oregon river reaches sampled in the summers of 1997 and 1998. Open circles represent pilot sites sampled in 1994 that were not resampled in 1997 or 1998; three other pilot reaches were part of reaches sampled in 1997.

veys occurred during July–September 1997 and 1998 and required having two persons in each of two rafts, with one crew collecting habitat data and the other collecting fish data.

We were requested by the USEPA to determine the electrofishing distance that, 75% of the time, would produce at least 95% of the fish species observed from sampling 100 channel widths (or all day) in representative Oregon river reaches. The USEPA branch chief who requested this study acknowledged that we would rarely collect all fish species in all reaches but settled on 95% of species 75% of the time as reasonable approximations. The initial sampling distance standard of 100 channel widths was based on a pilot study of six nearby rivers, plus information from wadeable streams

TABLE 1.—Habitat characteristics of 45 randomly selected Oregon river reaches sampled in the summers of 1997 and 1998.

Variable	Mean	Range	SD
Mean wetted width (m)	52	7–210	40
Mean thalweg depth (m)	1.5	0.6–4.0	0.9
Mean nearshore depth (m)	0.8	0.4–2.0	0.36
Mean slope (%)	0.8	0.2–2.6	0.6
Sinuosity (channel : straight line ratio)	1.4	1.0–3.4	0.4
Thalweg dominant substrate diameter ($\log_{10}$; mm)	1.7	0.1–3.8	1.0
Littoral large woody debris cover (% of area)	0.03	0.0–0.2	4
Mean shoreline riparian canopy cover (% of area)	36	0.9–76	21
Specific conductance (μS/cm)	93	38–310	55
Dissolved oxygen (mg/L)	8.9	6.6–10.6	1.0
Water temperature (°C)	19.2	9.4–26.6	4.2
Total phosphorus (μg/L)	46	5–485	75
Total nitrogen (μg/L)	193	5–648	151
Dissolved organic carbon (mg/L)	1.4	0.5–4.0	0.7
pH	8.1	7.3–9.1	0.5
Chloride (μeq/L)	79.3	8.8–202	63.1

where a distance of 40 channel widths approached an asymptote in fish species richness (Reynolds et al., in press). We limited sampling time to one workday because more information is acquired by visiting new reaches on subsequent days than by spending additional time at the same reach.

Environmental conditions.—Physical habitat data were collected along the thalweg at every half channel width and from 11 transects 10 channel widths apart (Peck et al. 2001). Maximum (thalweg) depth was measured at 200 evenly spaced points along the reach. Habitat types, the location and amount of woody debris, and predominant thalweg substrate were estimated visually or with a sounding rod and recorded while measuring the thalweg depths. Data collected at transects included channel dimensions (width, nearshore depth, bank angle, incision height), nearshore substrate, riparian vegetation cover and structure, channel gradient and bearing (for calculating sinuosity), and the occurrence and proximity of riparian human disturbances (e.g., roads, buildings, agriculture, and riprap).

Water samples were collected in a 4-L cubitainer and in two 60-mL syringes filled from a flowing area at the downstream end of each reach (Peck et al. 2001). Syringes were sealed to prevent gas exchange, and all water samples were placed on ice and sent by overnight courier to our analytical laboratory. Syringe samples were analyzed for pH and dissolved inorganic carbon. The cubitainer samples were split into aliquots and preserved within 72 h; they were then analyzed for alkalinity with Gran titration, for major anions with ion chromatography, for base cations by atomic absorption, and for total N and P through persulfate oxidation and colorimetry (USEPA 1987). At each transect, temperature, conductivity, and dissolved oxygen were measured with a YSI model 85 field meter.

Fish assemblages.—Fish were collected by electrofishing continuously along one randomly selected bank for a distance equal to 100 times the mean wetted channel width (Peck et al. 2001). Topographic maps were used to estimate average reach widths and to determine launch sites and landings that would bracket sample reaches. Wetted widths were measured at several points with a laser range finder while rowing to the study reaches, and sampling distances were calculated from these measurements. Each reach was broken into 10 continuous electrofishing subreaches, each 10 channel widths long and located between the 11 cross-channel transects used in sampling habitat. The data for each subreach were recorded separately to enable species−effort calculations.

The rafts were 3.7 m wide and 4.3 m long and were equipped with a rowing frame, a frame-mounted generator, a control box, a live well, port and starboard cathode arrays of aluminum conduit, and two anode arrays of steel cable extending in front of the bow. A single netter collected fish while the rower maneuvered the raft downriver at a speed slightly greater than the river velocity. We used a Smith-Root model 2.5 GPP set at pulsed DC (30 or 60 pulses per second) and 400–1,000 V, as required by varying conductivities (Table 1), to roll fish but minimize injury. Electrofisher clock times typically ranged from 1 to 2 h/d, which translated into 6–8 h of sampling time for the entire reach. All retrieved fish were identified and counted. Voucher specimens for each species were preserved in 10% solutions of buffered formalin and placed with the Oregon State University Museum of Ichthyology; species too large for collection jars were photographed.

Data analyses.—We plotted species−effort curves for each reach and for the pooled set of reaches for which we had data from 10 complete subreaches. Reaches in which sampling was interrupted or shortened by inadequate access or egress, inaccurate initial width estimates, swimmers, impassable obstacles, or gear malfunctions were not included in the pooled curves, thereby resulting in 35 reaches and 10 revisits with sufficient data. We calculated a species−effort curve for each reach based on rates of species accumulation versus sampling effort, the latter of which was estimated both by the cumulative length of subreaches and by the number of individuals collected.

To serve as an additional reference for the adequacy of our level of effort, we also estimated true species richness, or the number of species that are likely present in a sampled reach. Ten different estimates of true species richness were calculated from the observed species richness by means of EstimateS (Colwell 1997) and the Jaccard coefficient (Cao et al. 2001). All 10 richness estimators have been commonly used in the ecological literature. Estimates of true species richness account for species that are likely present but not observed. Each estimate was based on means calculated from 1,000 randomizations of the original subreach data. The mathematical formulations for the different estimators are as follows (variable definitions are given at the end of the list; see the EstimateS website and Cao et al. 2001 for additional details): Chao and Lee's abundance-based coverage estimator:

$$S_{abund} + S_{rare}/(1 - F_1/N_{rare}) + F_1(\text{CV of } F_1\text{s})/(1 - F_1/N_{rare});$$

Lee and Chao's incidence-based coverage estimator:

$$S_{freq} + S_{infreq}/(1 - Q_1/N_{infreq}) + Q_1(\text{CV of } Q_1\text{s})/(1 - Q_1/N_{infreq});$$

Chao's abundance-based estimator:

$$S_{obs} + F_1^2/2F_2;$$

Chao's incidence-based estimator:

$$S_{obs} + Q_1^2/2Q_2;$$

Burnham and Overton's first-order jackknife incidence-based estimator:

$$S_{obs} + Q_1 \cdot [(m - 1)/m];$$

Smith and van Belle's second-order jackknife incidence-based estimator:

$$S_{obs} + \{Q_1(2m - 3)/m - Q_2(m - 2)^2/[m(m - 1)]\};$$

Smith and van Belle's incidence-based bootstrap estimator:

$$S\text{obs} + S_{k=1,S_{obs}} (1 - p_k)^m;$$

Michaelis-Menten estimator for each randomization run:

$$S_n \cdot [(1 + n/n_{50})/(n/n_{50})];$$

Michaelis-Menten estimator for the mean species accumulation curve:

$$S_n \cdot [(1 + n/n_{50})/(n/n_{50})];$$

Cao et al.'s incidence-based Jaccard estimator:

$$[0.5(a + b) + c]/[c/(a + b + c)].$$

The variables are defined as follows:

S_{abund} = number of species with >10 individuals when all samples are pooled;
S_{rare} = number of species with ≤10 individuals when all samples are pooled;
F_i = number of species with i individuals when all samples are pooled;
N_{rare} = total number of individuals belonging to rare species that are not singletons;
CV = coefficient of variation (100·SD/mean);
S_{freq} = number of species found in >10 samples;
S_{infreq} = number of species found in ≤10 samples;
Q_j = number of species that occur in j samples;
N_{infreq} = total number of occurrences of infrequent species that are not unique;
S_{obs} = total number of species observed;
m = total number of samples;
p_k = proportion of samples with species k;
S_n = number of species observed after n sampling units;
n_{50} = number of sampling units to detect 50% of true species richness;
a = number of species unique to replicate 1;
b = number of species unique to replicate 2;
c = number of species common to both replicates.

We examined correlations between the environmental variables and the electrofishing distance (expressed in channel widths) required to capture 95% of the species observed in the full 100 channel widths sampled (CW_95). Included in this analysis were 21 chemical variables and 400 channel and riparian habitat variables, along with elevation, latitude, longitude, stream order, and sampling date. To evaluate associations between sampling distance requirements and environmental factors, we conducted a principal components analysis (PCA) on the 37 variables that were most highly correlated with CW_95. We excluded chemical and geographic variables because they had low correlations with CW_95. We included multiple variables for river size, slope, velocity, substrate size and stability, fish cover complexity, bank condition, sinuosity, riparian vegetation, and human disturbances of the riparian zone.

Results

Environmental Correlates with Sampling Effort

We found no strong correlations (Pearson r) between environmental conditions and sampling effort. Positive correlations (influences potentially increasing the required sampling distance) were between +0.30 ($P = 0.07$) and +0.37 ($P = 0.03$) and were primarily those describing high shear stress, fast water, coarse substrates, bank revet-

TABLE 2.—Most commonly occurring and dominant fish species collected from 45 randomly selected Oregon river reaches sampled in the summers of 1997 and 1998. Occurrence frequency is the percentage of reaches at which a species was collected; dominance frequency is the percentage of reaches at which that species was more abundant than any other fish species.

Species	Occurrence frequency (%)	Dominance frequency (%)
Rainbow trout *Oncorhynchus mykiss*	64	16
Largescale sucker *Catostomus macrocheilus*	61	14
Reticulate sculpin *Cottus perplexus*	55	9
Northern pikeminnow *Ptychocheilus oregonensis*	55	0
Speckled dace *Rhinichthys osculus*	50	7
Redside shiner *Richardsonius balteatus*	48	23
Torrent sculpin *Cottus rhotheus*	48	2
Chinook salmon *Oncorhynchus tshawytscha*	43	2
Pacific lamprey *Lampetra tridentata*	41	0
Longnose dace *Rhinichthys cataractae*	39	7
Cutthroat trout *Oncorhynchus clarki*	34	2
Chiselmouth *Acrocheilus alutaceus*	32	0
Mountain whitefish *Prosopium williamsoni*	27	5
Smallmouth bass *Micropterus dolomieu*[a]	25	11
Largemouth bass *Micropterus salmoides*[a]	18	0
Common carp *Cyprinus carpio*[a]	18	0
Western brook lamprey *Lampetra richardsoni*	18	0
Bridgelip sucker *Catostomus columbianus*	16	0
Bluegill *Lepomis macrochirus*[a]	16	0
Yellow bullhead *Ameiurus natalis*[a]	14	0
Mountain sucker *Catostomus platyrhynchus*	11	0
Sand roller *Percopsis transmontana*	11	0
Prickly sculpin *Cottus asper*	11	0
Shorthead sculpin *Cottus confusus*	9	0
Brown bullhead *Ameiurus nebulosus*[a]	9	0
Paiute sculpin *Cottus beldingi*	7	7

[a] Alien to Oregon.

ment, channel constraint, deep littoral areas, and riparian human disturbances. Negative correlations (influences potentially decreasing the required sampling distance) ranged from -0.30 (P = 0.07) to -0.45 (P = 0.006) and were generally those describing large woody debris, overhanging vegetation, and aquatic macrophytes, all of which were associated with low water velocities and greater fish cover. Less than 20% of the CW_95 variance was accounted for by these associations, which suggests that they had little value for predicting the necessary sampling distance.

Based on the 37 variables having the highest correlations with CW_95, the first five PCA factors described 76% of the total variance in environmental variables. The CW_95 was most significantly correlated ($r = +0.35$, $P = 0.03$) with factor five, which was associated with human disturbances in the nearshore zone (factor loadings were 0.66–0.71). The CW_95 was also correlated ($r = +0.32$, $P = 0.05$) with factor one, which was most strongly associated with variables describing the size and power of rivers (width, substrate size and stability, and residual pool depth) and had factor loadings from 0.58 to 0.85. Our results from the PCA were similar to those from simple correlation and general observation. The number of channel widths needed to collect 95% of the fish species increased as river size, littoral depth, velocity, and nearshore anthropogenic disturbance increased. The CW_95 decreased with increased fish cover. However, PCA axes predicted no more than 12% of the variance in sampling effort needed to collect 95% of the fish species observed.

Fish Assemblages

Sampling produced the fish assemblages expected in Oregon rivers. The sampled reaches yielded 2–16 fish species, with an average of 9. Five fish species (rainbow trout *Oncorhynchus mykiss*, largescale sucker *Catostomus macrocheilus*, reticulate sculpin *Cottus perplexus*, northern pikeminnow *Ptychocheilus oregonensis*, and speckled dace *Rhinichthys osculus*) were collected at 50% or more of the reaches (Table 2). The largescale sucker and northern pikeminnow are common large-river species in the Columbia River drainage, while the others are widespread in Oregon streams and rivers. Four species (redside shiner, rainbow trout, largescale sucker, and small-

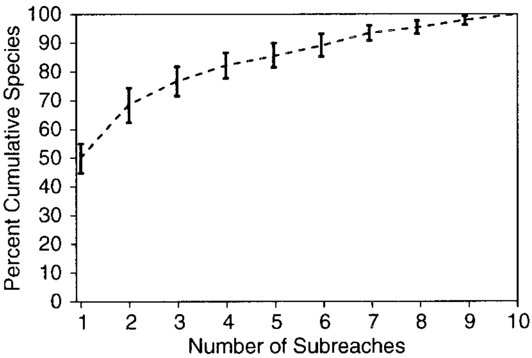

FIGURE 2.—Number of electrofishing subreaches needed to collect 95% of the fish species collected in a distance equal to 100 times the mean wetted width of the channel for 35 randomly selected Oregon river reaches sampled in the summers of 1997 and 1998. The dotted line joins the means; the vertical lines represent standard errors.

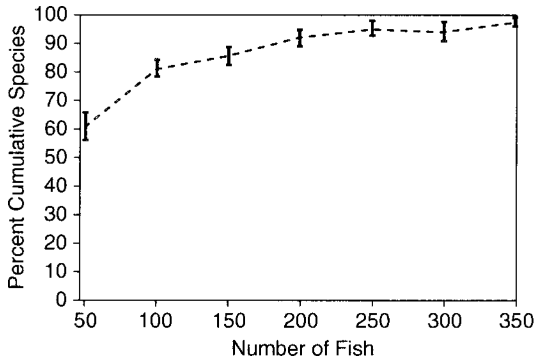

FIGURE 3.—Number of individuals needed to collect 95% of the fish species collected in 100 channel widths for 35 randomly selected Oregon river reaches sampled in the summers of 1997 and 1998. The dotted line joins the means; the vertical lines represent standard errors.

mouth bass) were the most abundant species collected at 10% or more of the reaches (Table 2). In addition, 6 alien species (smallmouth bass, largemouth bass, common carp, bluegill, yellow bullhead, and brown bullhead) occurred at 9% or more of the river reaches sampled.

Raft electrofishing commonly produced several small benthic species (reticulate sculpin, speckled dace, torrent sculpin, Pacific lamprey, longnose dace, western brook lamprey, sand roller, prickly sculpin, shorthead sculpin, and Paiute sculpin). Although the abundances of these species were likely underrepresented, they were frequently collected and occasionally were even numerically dominant (e.g., reticulate sculpin, speckled dace, torrent sculpin, longnose dace, and Paiute sculpin). However, we never collected white sturgeon *Acipenser transmontanus*, which occurs in some deep pools in these reaches.

Sampling Effort

Catches were consistent along the 10 subreaches sampled throughout the day, with no trend or large differences in the numbers of fish collected in upstream and downstream subreaches. The mean ($\pm$SE) catch for the 45 reaches was 24.6 $\pm$ 2.5 individuals per subreach, with a range of 20.5–28.3 individuals.

When all 35 reaches with 10 subreaches sampled were examined, we found that on average 8.5 subreaches (85 channel widths) produced 95% of the species collected in the entire reach (Figure 2). In some cases, no species were added after two subreaches, while in other cases new species were added throughout the reach. In general, the asymptote was approached with little effort at reaches with few species, slow water, and highly homogeneous physical habitat; by contrast, larger, faster, more complex rivers required proportionately greater effort, probably because it was more difficult to maneuver the raft and to see and net fish in the fast water. On average, 95% of the observed species were detected when more than 225 individuals were collected (Figure 3).

Sampling Precision and Accuracy

The above estimates of necessary sampling effort are of little value without an estimate of sampling variation (including both sampling period variation and measurement variation). Revisits to six reaches produced the same number of species or a difference of only one species (Table 3); at three reaches the difference was two to three species, while at one reach the difference was five species. In the latter case, flow and temperature changed substantially as a result of increased September reservoir releases. These changes were accompanied by the addition of three salmonid and two benthic species.

Simulated estimates of true fish species richness were usually only slightly higher on average than the number of species that we actually collected from the rivers (Table 3). Usually 0–3 more species were predicted for the reaches than we found, although the difference increased as species richness increased. Six reaches (97–458, 97–450, 97–430, 98-S02, 98–113, and 98–009) had more than two estimates of true species richness that were 5–18 species more than the number we captured. These reaches are in the Willamette or Umpqua

TABLE 3.—Number of species and individuals collected from 35 randomly selected Oregon river reaches sampled in the summers of 1997 and 1998, plus statistical estimates of true species richness. Estimates were generated from EstimateS (Colwell 1997) and Cao et al. (2001) based on 1,000 randomizations; a = visit 1, b = visit 2. The following abbreviations are used for the species richness estimators: ACE = Chao and Lee's abundance-based coverage estimator; ICE = Lee and Chao's incidence-based coverage estimator; Chao1 = Chao's abundance-based estimator; Chao2 = Chao's incidence-based estimator; Jack1 = Burnham and Overton's first-order jackknife incidence-based estimator; Jack2 = Smith and van Belle's second-order jackknife incidence-based estimator; Bootstrap = Smith and van Belle's incidence-based bootstrap estimator; MM-run = Michaelis-Menten's randomization run estimator; MM-mean = Michaelis-Menten's mean species accumulation curve estimator; Jaccard = Cao et al.'s incidence-based Jaccard estimator. See text for mathematical formulations and references.

					Estimates of true species richness									
Reach	Species observed	Individuals observed	Singles	Doubles	ACE	ICE	Chao1	Chao2	Jack1	Jack2	Bootstrap	MM-run	MM-mean	Jaccard
97-S02	12	191	2	0	13	13	14	14	14	15	13	14	13	13
97-S01	11	147	2	2	13	14	11	12	14	15	12	13	13	12
97-460	10	70	1	0	11	10	11	10	11	11	16	13	12	11
97-458 a	10	175	3	0	14	12	15	15	13	15	11	11	10	14
97-458 b	9	242	2	0	10	10	11	10	11	12	10	10	10	11
97-450 a	11	153	3	2	15	17	12	24	16	20	13	13	12	16
97-450 b	12	355	4	0	22	16	20	16	16	18	14	14	13	16
97-449 a	11	173	1	1	11	12	11	13	13	14	12	13	13	12
97-449 b	16	383	3	1	19	18	18	17	19	19	17	18	18	19
97-447	9	189	3	0	12	12	14	11	12	13	10	10	10	11
97-444	10	155	0	1	10	10	10	10	10	9	10	12	12	11
97-430	16	164	3	0	17	19	21	20	20	22	18	21	20	18
97-429	6	96	2	1	8	8	7	7	8	9	7	7	7	7
97-420	6	161	1	0	7	7	7	7	7	8	6	6	6	7
97-311	3	203	0	0	3	3	3	3	3	3	3	3	3	3
97-250	12	318	1	2	12	14	12	13	15	16	13	15	14	15
97-243	6	147	0	0	6	6	6	6	6	5	6	8	7	7
97-216	8	632	1	0	9	8	9	9	9	10	8	9	8	9
97-215	12	224	1	0	12	13	13	12	14	13	13	14	14	13
97-208 b	3	72	1	0	4	4	4	4	4	5	3	3	3	4
97-208 a	2	70	0	0	2	2	2	2	2	2	2	2	2	2
97-179	9	296	2	2	11	11	9	9	11	10	10	11	11	12
97-070	8	327	0	0	8	8	8	8	8	7	8	9	9	8
97-028	8	576	1	1	9	8	8	8	9	9	9	8	8	9
97-020	5	91	0	1	5	6	5	6	6	7	5	6	6	6
98-S02	10	103	2	1	11	13	11	12	13	14	12	20	16	11
98-191 b	6	102	1	0	7	7	7	6	7	7	7	7	7	7
98-191 a	6	242	1	0	7	6	7	7	7	8	6	6	6	7
98-181	16	344	3	1	19	19	18	18	20	21	18	19	19	19
98-179 b	9	206	1	0	10	10	10	9	10	9	10	11	11	10
98-179 a	11	258	2	1	12	13	12	16	14	16	12	12	12	13
98-175	12	334	2	2	13	15	12	13	15	16	13	15	14	15
98-135	10	268	2	0	12	11	12	11	12	13	11	11	11	12
98-133 b	10	245	0	0	10	10	10	10	10	10	10	13	12	12
98-133 a	10	159	1	1	11	13	10	11	13	14	11	13	12	12
98-117	8	260	2	0	12	9	10	9	10	11	9	9	9	10
98-113 b	8	163	4	1	14	15	12	12	12	14	10	11	9	13
98-113 a	5	121	1	0	6	6	6	5	6	6	6	6	6	6
98-103	8	71	1	2	9	11	8	10	11	12	9	11	10	12
98-091 b	5	236	0	0	5	5	5	5	5	4	5	6	6	6
98-091 a	7	329	2	0	8	8	9	9	9	10	8	8	8	9
98-067	8	186	1	1	9	9	8	8	9	9	9	11	10	9
98-029 b	10	174	0	2	10	10	10	10	10	8	10	12	12	11
98-029 a	11	176	2	2	13	14	11	12	14	15	12	13	12	14
98-027	9	180	0	0	9	9	9	9	9	7	9	10	10	10
98-009	14	355	6	2	32	24	19	25	20	25	17	16	15	21

valleys and have complex channels and a larger species pool. The second-order jackknife estimated lower true species richness than we observed at six reaches.

Discussion

Environmental Correlates with Sampling Effort

Although associations between habitat conditions and the sampling distance needed to collect 95% of species counted in a day are of ecological and practical interest, all of the correlations were extremely weak. Over 80% of the CW_95 variance was not accounted for by these associations, meaning that habitat would not be useful for predetermining sampling effort. Also, as explained by Allen et al. (1999) and Kaufmann et al. (1999), we should not expect high correlations of CW_95 with environmental variables when we observe an among-reach-to-within-reach variance of only 0.24 for CW_95. In other words, there was four times as much within-reach variance (measured as the temporal and measurement variance among subreaches at a reach) as there was among-reach variance in the distance needed to collect 95% of the species. High within-reach variance occurred because there were considerable differences between the repeat samples in the number of channel widths required to capture 95% of the species at a reach. Because of sampling imprecision, fish movements, or both, crews would sometimes collect all the species at a reach in a fraction of the distance required in another visit. Such within-reach and within-season variance may be partly why Gammon (1976) and Yoder and Smith (1998) routinely sampled shorter reaches three times in a summer. Furthermore, the strongest predictors of the required sampling distance were variables that were measured in the field while fish were being sampled. The requirement of field measurements hinders advance determination of sampling distance on a reach-by-reach basis, as noted by Lyons (1992). Also, if environmental conditions and fish assemblages were not sampled at the same times and places, interpretations would be further clouded.

Fish Assemblages

The widespread occurrence of six alien (nonnative) fish species in Oregon rivers is a growing concern, especially given that only two were on an earlier list of most frequently collected species (Bond et al. 1988). The widespread presence of smallmouth bass in Oregon rivers suggests a potential hazard to native fish because it is an alien piscivore and was not present in 1983 at one of the reaches where it is now dominant. In other words, several alien species appeared to be expanding their ranges, and smallmouth bass is becoming dominant in some rivers. Miller et al. (1989) listed alien species as a detrimental factor in 68% of fish extinctions, and Whittier et al. (1997) reported that alien fishes were associated with the regional extirpation of native minnows. Although the changes that we observed reflect improved fishing for alien warmwater game fish, their potential prey (native cyprinids, cottids, and juvenile salmonids) may be at risk.

Sampling Effort

The consistency of our revisit samples, along with our ability to capture fish representing a wide range of habitat types and sizes, gave us confidence in our ability to accurately estimate the presence of and the effort necessary to collect all but rare species.

Collecting all rare species would involve substantially greater effort. Using a subset of the same data and the Jaccard coefficient, Cao et al. (2001) concluded that a sampling reach of 100 channel widths underestimated true species richness. They determined that an average of 286 channel widths (ranging from 70 to 1,383) would be required to collect all of the species actually present. Our 100 channel widths yielded an average of 84% of true species richness, ranging from 60% to 99%. Thus, for a river reach supporting 20 fish species, electrofishing 100 channel widths would be expected to yield the 17 most common species and to miss 2 or 3 of those species occurring at a rate of less than 2 per 100 (see also Table 3).

We found that capturing an average of 225 individual fish was sufficient to collect 95% of the species caught by greater effort (up to 350 individuals). However, our reaches did not include extremely slow and productive rivers found elsewhere, and our sampling did not involve the use of multiple gears. In those cases, 225 individual fish and 16 fish species could be captured within a single habitat type or from a single seine haul (Yoder and Smith 1998). Pilot surveys should be conducted in such systems, or sampling should be intensive (40–100 channel widths) to ensure that sampling includes representatives of the common geomorphic habitat units present in a river reach.

Some reaches had markedly different habitat types along the left and right banks, especially where land use or shading differed between the banks along the entire reach as well as in channelized rivers and those in which microhabitats such as scour pools, snags, and weed beds were rare. We agree with Yoder and Smith (1998) that such habitats should be sampled and recommend alternating sides every two transects. In addition, where strong upstream eddies allow it, we recommend rowing the raft upstream a few meters and sampling rapids twice. We sampled very few rivers with highly braided channels or complex off-channel habitats (alcoves, ponds); such systems could also require alternative sampling methods. Schiemer (2000) reported that the presence or absence of such habitats may be reflected in the fish assemblage of the main channel, but Schmutz et al. (2000) argued for direct sampling of all habitat types.

Researchers with differing objectives may determine that it is more informative to sample more reaches in a day with less effort and precision than would be required to obtain accurate and repeatable estimates of species richness at a single reach. Greater sampling intensity in a smaller area, including the use of multiple gears and revisits, could reduce the recommended sampling distance and may be necessitated by different objectives and sampling designs. However, Penczak and Zalewski (1973) found that the first electrofishing pass in a large Polish river produced an average of 81% of the species found in three passes and in nets. Working with small streams, Paller (1995) also found that sampling a large area with a single pass produced more species than did sampling a small area intensively. Similarly, Matthews (1990) found that spatial variance was greater than temporal variance and suggested that in fish surveys it is better to increase the number of sampling sites than the number of visits per site.

Regional Applicability

We are confident that the sampling distance estimates developed from this study are representative of Oregon rivers and higher-gradient western U.S. rivers in general. The reaches were selected through a spatially balanced, randomized sample of all mapped rivers in Oregon that were greater than fourth order on 1:100,000 scale maps, which insured that the reaches were representative of all Oregon rivers. The reaches occurred in all eight level III ecoregions of Oregon and half the level I ecoregions of the western United States (Omernik 1987; CEC 1997). Such a diversity of river sizes, physical and chemical habitats, and locations should make our results applicable to a large portion of the West. In this study, catch rates were consistent, small benthic fishes and midwater species were collected, estimates of species richness as indicated by repeat samples were precise, and observed values for species richness compared well with nonparametric estimates of true species richness, indicating that they were reasonably accurate. We believe that such results further support the applicability of our results to western rivers sampled during summer base flow periods.

We conclude that 85–100 channel widths should usually be a sufficient sampling distance for precise and accurate estimates of common fish species richness at reaches on western U.S. rivers. On large rivers like the Willamette and Umpqua, this translates into sampling 8–10 river kilometers, which is well within normal fishing and canoeing drifts and launch spacings of approximately 16 km. Our recommended sampling distance is not applicable to major rivers like the lower Columbia, Fraser, Snake, or Colorado, which are much larger than our sample rivers. We suspect that the sampling distance for rivers needs to be twice that which is often recommended for wadeable streams because we only sampled one side of the rivers whereas much of the surface areas of wadeable stream reaches are typically sampled. However, Mann and Penczak (1984) intensively electrofished a river 54–70 m wide and collected only 6.6% of the fish in the center versus 82.6% from the margins. If accurate and precise estimates of true species richness are desired, Cao et al. (2001) estimated that an additional 200 channel widths (and two more days) of raft electrofishing would be needed to produce the additional two to five rare fish species expected. Recognizing that 100 channel widths of electrofishing effort were marginal for estimating true species richness in this study, we are surveying 300 channel widths on eight of the largest rivers in our sample.

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